Water Quality of Texas Bays*
(Nutrients, Trace Elements and Toxic Compounds)

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This manuscript is designed to compare the nutrient balances and trace element significance in Texas Bays and Estuaries. The task of assigning water quality criteria in all estuarine waters rests with the federal Environmental Protection Agency. However, the Texas Bays and Estuaries represent a unique range of environments of the U.S. Coast that stand alone and therefore must be assigned standards appropriate to the environment.

Therefore we have compared several Texas Bays relative to nutrients and trace elements through an analysis of data from our files, a life history data bank from literature survey, a study of the Corpus Christi area, personal communication with a wide range of individuals and information from the Texas Water Quality Board, Texas Water Development Board, the U.S. Geological Survey and the State Health Department.

The following two sections, we hope will provide some guidelines for the evaluation of the Galveston Bay in terms of water quality standards. The large amount of environmental data available for the Texas Bays and Estuaries allow an estimate at this point in time, that will be subject to modification as new information is obtained. We should also point out that such evaluations as this do point out needs for future research.

*Taken in part from a report on Development of Biological Criteria, Establishment of Guidelines for Texas Coast Management IAC-(74-75)-0685 NSF RANN-61-34870x.

Nutrient Balances, Productivity and Organic Carbon Cycles

Productivity and the balance of nutrients in their various cycles are valuable concepts for discussion of estuarine management. Analysis of productivity reveals information on the energy and nutrient flow through the estuary. Nutrients are regarded as governing agents because of their nature in limiting plant growth in the aqueous environment.

The following discussion is developed as an approach to understand the carbon-nutrient balance of the Texas Bay systems. While a large amount of information is obviously available, our treatment should be considered as a preliminary mechanism for such logical development of cycles. For example there is very little information on the magnitude of export of fish and crustaceans from the bay systems during normal migration patterns and the loss through predation before they and the larval forms resulting from offshore spawning return to the bay system. We would hope that the following discussion would indicate the needs for new information to provide more complete analysis of the bay dynamics. The results of our analyses should be considered a minimum basis for decision making, and as such, are significant to allow some pertinent conclusions to be made.

The analysis of productivity will be accomplished by the examination of known values for production, consumption, import and export of carbon. The next step will be to evaluate the impact of each of these parameters and how they might be managed as estuarine gains and losses.

The discussion of nutrient balance in the estuarine system will be weighed toward nitrogen. The widely recognized role of nitrogen as a limiting nutrient in estuaries (Ryther and Dunstan, 1971; Smith, 1973) was the reason for its selection in this discussion. Local information is compared with recent recommendations concerning nitrogen for water quality management in Chesapeake Bay (Clark, et al., 1973).

Productivity and Organic Carbon Cycles

Considerable information is available concerning gross productivity in the Texas coastal bay system. Some results have been published as either carbon, oxygen or both, produced per unit of area or volume. Others have been published as standing crop of chlorophyll a and the attendant assimilation quotient. In order to standardize and tabulate the existing data, the following assumptions were made: 1. One gram of carbon fixed by plants during photosynthesis results in the release of three grams of oxygen gas (Finenko and Zaika, 1970). 2. The amount of carbon assimilated per gram of chlorophyll a is 2 grams per hour of daylight (Odum, et al., 1958). 3. The ratio of moles of oxygen gas produced per mole of carbon assimilated, that is, the photosynthetic quotient, is one (Cox, 1967). 4. Productivity values reported on a volume basis were corrected to an area basis using the average bay system depths from Table 1.

A comparison was made of planktonic gross photosynthetic production for Corpus Christi, Galveston and San Antonio Bays. The results of this comparison are shown in Table 2. These three bays have been extensively studied by State agencies and represent the range of size, peripheral development and freshwater inflow values found in the Texas coastal zone. As can be seen from Table 1, gross productivity in Galveston Bay, on an area basis, is double that of Corpus Christi Bay and nearly six times that of San Antonio Bay. Total

TABLE 1 Physical factors for selected Texas coast bays.

Bay System	Area 10^3 acres	Area km^2	Depth ft.	Depth M	Volume 10^6 acre-ft	Freshwater Inflows + rainfall 10^6 acre-ft/yr (c)	"Flushing" Time (d) Years
Corpus Christi-Nueces (a)	134	540	7.6	2.3	1.02	1.03	0.99
Copano-Aransas (a)	140	570	5.9	1.8	0.83	0.59	1.4
San Antonio (a)	143	580	4.0	1.3	0.572	1.9	0.30
Lavaca-Matagorda (a)	238	960	5.9	1.8	1.40	1.8	0.78
Galveston (b)	333	1,347	8.0	2.4	2,664	11.6	0.23

notes - a- Davis, 1973. b-Espey et al., 1971. c-Texas Water Plan, TWDB, 1968.
d- This rate is computed by dividing volume by inflow; the actual flushing time would be much less due to lunar and wind-driven tidal exchange. Use of this figure is for comparison only.

TABLE 2 Comparison of gross planktonic production for San Antonio, Corpus Christi and Galveston Bays

Bay	grams C / m² day	pounds C / acre day	kg C / year	pounds C / year
San Antonio[1]	1.0	8.93	2.12×10^{8}	4.66×10^{8}
Corpus Christi[2]	2.52	22.20	3.89×10^{8}	8.55×10^{8}
Galveston[3]	5.87	52.46	2.90×10^{9}	6.37×10^{9}

[1] Davis, 1971; Jack Nelson, Texas Water Development Bd., personal communication.

[2] Davis, 1971; Odum, E.P., 1959; Odum, McConnell & Abbott, 1958; Odum, *et al.*, 1963; Odum & Wilson, 1962; Hellier, 1962; Odum, H.T., 1967.

[3] Armstrong & Hinson, 1973; Espey, *et al.*, 1971; Corliss & Trent, 1971.

gross production of Galveston Bay is seven times that of Corpus Christi Bay and nearly fourteen times that of San Antonio Bay.

Biotope specific productivities calculated for Corpus Christi Bay are shown in Table 3. While salt marsh and grass flat biotopes have the highest gross productivities per unit area, the bay planktonic biotope contributes the largest fraction of the total gross production. As can be seen from Table 3, the gross productivity of Corpus Christi Bay totals 1.21×10^9 pounds of carbon per year or 3.3×10^6 pounds per day.

The metabolic balance in Texas bays is autotrophic. The ratio of production to respiration is approximately one (Odum and Hoskin, 1958; Odum and Wilson, 1962), especially in regard to the bay planktonic biotope. A partial verification of this may be found in comparing the gross productivity with the amount of carbon introduced by man as organic wastes or entering the bay as runoff. A P/R ratio of "one" would suggest a low external supply of carbon. Waste discharges in Corpus Christi Bay account for 5.04×10^5 pounds of carbon per year (*J. S. Sherman, Water Needs Task Force, personal communication). This is 0.04% of the annual gross production. For comparison, Galveston Bay, with much more peripheral development, receives an amount equivalent to 2.1% of annual gross productivity from waste discharges (Armstrong and Hinson, 1973). A computation of organic matter received in Corpus Christi Bay from runoff can be made using average Nueces River flow information (Davis, 1973) and the organic loading factor used by the Estuarine Modeling Task Force (*George Murfee, personal communication). The organic matter contributed by runoff according to these calculations,

*NSF-RANN Grant GI 34870X and grant from Office of the Governor of Texas IAC (72-73)-806.

TABLE 3 Gross production by biotope for Corpus Christi Bay.

Biotope	Mean Productivity gmC/m² / day	lbC/A / day	Samples	Min. gmC/m² / day	Max. gmC/m² / day	S.D. gmC/m² / day	Acres	lbC/yr.	KgC/yr
Bay Planktonic[1]	2.51	22.3	30	0.09	8.87	2.53	105,456	8.55×10^8	3.89×10^8
Grassflat[2]	3.83	34.2	11	0.8	11.4	3.1	18,894	2.36×10^8	1.07×10^8
Saltmarsh[3]	3.70	33.0	6	0.31	7.44	3.0	7,579	9.13×10^7	4.15×10^7
Intertidal Flats[4]	0.90	8.03	5	0.41	2.35	0.82	8,980	2.36×10^7	5.48×10^8

[1]Davis, 1973; Odum, E.P. 1959; Odum, McConnell & Abbott, 1958; Odum et al., 1963; Odum & Wilson, 1962; Hellier, 1962; Odum, H.T. 1967.

[2]Odum, Burkholder & Rivero, 1959; Hellier, 1962; Odum, H.T. 1967; Copeland, 1965; Waite, 1972; Pomeroy, 1960; Odum & Hoskin, 1958; Odum, H.T. 1963; McMahan, 1968; Odum, McConnell & Abbott, 1958.

[3]Odum, McConnell & Abbott, 1958; Corliss & Trent, 1971; Williams & Murdoch, 1966; Keefe, 1972; Smalley, 1959.

[4]Copeland, 1965; Burkholder, Repak & Sibert, 1965; Pamatmat, 1968; Grøntned, 1960; Pomeroy, 1959.

amounts to 6.55×10^6 pounds of carbon per year or 0.54% of the annual gross productivity. This compares closely with the value of 0.4% for Galveston Bay (Armstrong and Hinson, 1973). These data confirm that imported organic carbon is a minor contribution to the carbon budget of both Corpus Christi and Galveston Bays. Also of interest is the much smaller organic waste loading in Corpus Christi Bay relative to Galveston Bay.

Turning from mechanisms that bring carbon into the bay to those which remove it, we find that one of the most easily quantified forms of carbon removal from the bay system is the commercial catch of fish, shrimp, crabs and oysters. These data are reported in the catch statistics published by the National Marine Fisheries Service. Table 4 shows the catch for several bays along the Texas coast for ten recent years. There are several points of interest in these data. There are large fluctuations in catch from year to year. Also, the catch of shrimp relative to fish is much larger in Galveston and San Antonio Bays.

The rate of carbon removal can be determined by using the ten year average catch for Corpus Christi Bay. This catch represents 5.83×10^4 pounds of carbon dry wt. per year, or 0.048% of the annual productivity as shown for all biotopes in Table 3. This value can be used only for Corpus Christi Bay as we have not made the same productivity calculations for all biotopes of Galveston Bay.

There are currently two estimates of harvest by sports fishing. The first is based on interpretation of a pilot creel census conducted in August, 1973. Details of this census are given in Chapter III. The preliminary report of the census estimates 12,206 pounds of fish

TABLE 4 Commercial Catches in Some Texas Bays

Commercial catch in thousands of pounds - Fish

year	Corpus Christi	Aransas-Copano	San Antonio	Galveston
1972	316.8	683.9	205.5	493.7
1971	216.5	626.1	259.6	212.2
1970	113.2	430.3	213.2	332.0
1969	91.7	728.2	84.7	556.7
1968	114.0	509.8	161.2	519.9
1967	250.8	327.7	287.9	767.9
1966	81.4	468.6	241.4	592.6
1965	59.1	551.4	79.4	875.5
1964	56.3	552.4	154.4	498.3
1963	78.0	866.0	189.6	219.4
10 yr ave	137.8	574.4	187.7	506.8

Commercial catch in thousands of pounds - Shrimp, Crabs and Oysters

year	Corpus Christi	Aransas-Copano	San Antonio	Galveston
1972	521.2	2,609.6	2,650.0	9,487.4
1971	203.9	1,044.5	1,986.2	11,199.3
1970	345.7	2,325.3	2,060.3	12,101.3
1969	479.8	1,503.1	2,636.7	9,438.7
1968	634.3	1,955.1	1,839.5	7,203.8
1967	514.7	647.5	1,813.8	6,228.5
1966	657.2	823.9	1,159.7	7,383.4
1965	567.2	985.3	2,376.5	10,600.1
1964	295.3	886.8	2,250.8	9,534.1
1963	236.5	482.1	1,436.0	6,736.8
10 yr ave	445.6	1,326.3	2,031.0	8,991.3

caught by sportsfishermen and is believed to represent 20% of the total sportsfishing catch of Corpus Christi Bay during the 28 day survey. Direct extrapolation to one year gives an annual harvest of 7.93×10^5 pounds of fish, or about 575% of the commercial harvest. However, comparison of the same sportsfishing data with the August commercial fish catch gives the ratio of 61,030 pounds of sports fin fish to 85,848 pounds of commercial fin fish or the sports catch was 71% of the commercial catch exclusive of shrimp, crabs and oysters. An earlier estimate of sports catch was made for Texas Parks and Wildlife Dept. (Belden Assoc., 1960). The sports catch of red drum, black drum, speckled trout and flounder for that year was about 700% of the commercial catch for these four species. From these data, the range of the annual sports catch varies from one to seven times the commercial fish catch exclusive of shrimp, crabs and oysters. Consequently, from 0.06% to 0.12% of the annual gross production of Corpus Christi Bay can be accounted for as removed by man's harvest of fish, crabs, shrimp and oysters. These figures overlook the catches by sports shrimpers. There are approximately 10,000 sports shrimpers licensed by the Texas Parks and Wildlife Dept. The Belden survey (1960) estimated sports shrimping catches at 1,500,000 to 3,000,000 pounds of shrimp per year, but admitted to a very small sample of sports shrimpers from which to base their estimates. It is understood that the Parks and Wildlife Dept. plans another survey of sports shrimpers in the near future.

Another parameter that may be considered in measuring the energy flow of the bay is the amount of carbon composing the standing crop of organic material. This may be measured from particulate and dissolved organic carbon analyses. Data Table 5 (Maurer, 1971;

Reimers, 1968; Wilson, 1962) give a standing crop for Corpus Christi Bay of 1.95×10^7 pounds of carbon. This can be compared with the daily carbon production values for the same area of 2.3×10^6 pounds to indicate a relatively rapid carbon turnover (Table 6). This analysis accounts for organisms up to the size of zooplankton, but not for the larger swimming organisms. Monthly values for fish biomass in the Laguna Madre (Hellier, 1962) vary between 18 and 337 pounds of fish per acre. The Laguna Madre has a higher density of fish than Corpus Christi Bay. However, if the Laguna Madre values were used for Corpus Christi Bay, the fish biomass contribution would be between 1% and 12% of the standing crop of carbon.

The time required for inputs and productivity to replace the carbon in the standing crop is called the residence time. Table 6 shows a sample calculation of residence time of carbon in several Bays, omitting fish biomass. In this case, residence time is 5.9 days for Corpus Christi. In the case where the maximum fish biomass is considered, the residence time becomes 7.1 days. The contribution of waste input carbon is so small as to have no effect on the residence time.

The final step in this analysis is to relate the importance of this information to management. Subject to man's control, the amount of carbon input as waste and extracted as harvest is so small relative to the carbon balance of the bay as to produce little effect. Other aspects of management which may have some significance are control of waste discharge quality, as opposed to the amount of carbon in the discharges, and enforcement of fishing laws to prevent ecological upset by over harvesting of some particular species. Otherwise, to reiterate, it does not appear from the data that man's influence over

Table 5

Dissolved and particulate organic carbon measurements - Texas coast

Wilson 1963 diss. total org C mg/l wet combustion

Area	date	min	max	ave.	N
Sabine Lake	Apr. 7,62	11.2	19.6	14.7	12
Galveston Bay	Feb 24, 62	3.4	20.0	8.7	15
Houston Ship C	"	8.8	11.0	10.1	4
San Antonio	Mar 10.62	7.2	39.0	16.4	9
Aransas Bay	"	4.0	8.4	5.87	3
Corpus Christi	17-18May 60	6.1	41.5	19.0	12
Laguna Madre	"	21.0	47.8	27.4	10
Baffin BAy	23 Apr. 60	80.0	91.0	85.5	2
Gulf off PA	20 Aug 60	1.3	2.8	2.0	11
CC Bay	12-17 Feb 62	3.6	11.6	6.3	17
CC Inner Harb.	12-17"	5.2	10.8	8.6	7
Redfish Bay-Intracoastal	"	5.5	9.4	7.3	8
Laguna Madre	"	7.0	16.4	9.3	10

Reimers, 1968
C C Bay

	DOC				POC			
	min	max	ave	N	min	max	ave	N
Feb 21 68	1.6	2.5	2.1	8	1.4	3.0	2.3	5
March 1 68	1.9	1.9	1.9	3	2.5	2.9	2.7	2
March 14 68	1.3	3.7	2.8	8	1.8	3.0	2.4	7
Apr 15 68	1,5	2.1	1.8	4	1.5	3.8	2.6	4
May 68	2.6	4.1	2.9	4	3.9	4.5	4.2	4

total ave. DOC = 2.3 POC = 2.7 TOC = 5.0

Maurer 1971 Dissolved Org C

Area	Date	min	max	ave	N
CC bay	prob 1970	4.2	5.9	4.8	3
Laguna Madee	"	3.6	11.1	7.1	15
Copano-Aransas	"	3.7	5.3	4.4	10
San Antonio	"	3.2	4.0	3.6	6
Matagorda	"	3.6	4.9	4.1	8

Galveston Bay Project TOC - Beckman

	min	max	ave	N
Jan 72	13	22	16.2	4
Apr. 72	34	43	39.1	6
July &2 72	31	87	52.2	5

E.M. Davis - survey C. C. Bay La Quinta channel area 7/72-6/73
T.O.C.
ave= 12.78 min = 5 max = 19 ppm C

TWDB unpublished surveys - J. Holland collection TOC 1972-73
Aransas-Copano Bay min=3.0 4/12/73, max= 68.0 8/15/73 avg = 21.7
Corpus Christi min=2.0 4/10/73, max= 63.0 7/12/73 avg = 19.8

the carbon balance of Corpus Christi Bay is of sufficient magnitude to be used as a management tool.

Nutrient Balances in Texas Bays

It is widely accepted that estuaries are highly productive because of high nutrient concentrations maintained by runoff and rapid recycling within the estuary. This is especially true of the Texas estuaries where offshore upwelling does not exist and primary nutrients originate from land. One of man's impacts on the coastal zone is to alter natural nutrient inflow, sometimes to the point where sewage or industrial wastes cause undesirable effects such as algal blooms. The task force on estuarine modeling of Corpus Christi Bay has worked out the reactions influencing the spatial variation of nutrients within the bay system. The purpose of this section is to provide an overview of the sources of nutrients and the pathways by which nutrients are lost, comparing Corpus Christi Bay with other Texas bays, and to attempt to integrate this information with the discussion of productivity.

One of the results will be to show that past productivity of our area has produced a fertile estuary. Now that man has altered the upland drainage by agriculture and water management measures such as dams, nutrient flow into the bays has changed. We would hope that an understanding of nutrient balances could be used as a tool to manage the flow of nutrients to the estuaries.

The amount of nutrients available to phytoplankton at any moment in time in the waters of Texas Bays can be evaluated from analyses for ammonia, nitrate, nitrite, phosphate and total phosphorus. Nutrient information has been compiled from Corpus Christi, San Antonio and

TABLE 7 Summery of Nutrient data, averages in mg/l

Bay System	Nitrogen Inorganic	Nitrogen Organic	Phosphorus Inorganic	Phosphorus Total
Corpus Christi-1952			0.04	
1972-73	0.18		0.015	0.04
1972	0.16	0.62	0.031	0.18
San Antonio-1970-71	0.61		0.13	
1972-73	0.28		0.16	0.20
Galveston Bay 1968-72				
Trinity Bay	0.39	.96		0.49
Main Galv.	0.44	.80		0.55
East Bay	0.16	.76		0.27
West Bay	0.13	.60		0.18

TABLE 8 Sources of nutrient data.

Bay System	Nutrients	Source	Retrieval & Analysis
Corpus	PO_4-P	Hood, 1952	manual average
"	NH_3, NO_3, NO_2	J. Holland, unpublished	TWDB Coastal
	PO_4, Total P Org. N	1972-1973 surveys	Data System
"	NH_3, NO_3, NO_2	E.M. Davis, unpublished	ENVIR Data Bank
	PO_4, total P	1972 surveys	
San Antonio	NO_2, NO_3, PO_4	Cechova & Davis (1973) 1970-71 survey	weighted average
"	NH_3, NO_2, NO_3	TWDB, unpublished 1972-73 survey	TWDB Coastal Data System
	PO_4, Total P		
Galveston	NH_3, NO_3	Galveston Bay Study 1968-1972 surveys	ENVIR Data Bank
	Total P, Organic N		

Galveston Bay. The average nutrient concentration averages are shown in Table 7. The data sources and data reduction methods are shown in Table 8. Table 9 is a summary of nutrient data for Galveston Bay.

In estuarine systems, the limiting nutrient is usually nitrogen. Smith (1973) reported that nitrogen was apparently limiting in Corpus Christi Bay, Aransas-Copano bays, San Antonio Bay and Matagorda Bay as shown by algal growth potential studies. Ryther and Dunstan (1971) suggested that nitrogen is usually the limiting factor for algal growth in the coastal marine environment. In a LSU Sea Grant Publication Aquanotes Vol 3 April 1974, Dr. Patrick reports that nitrogen is limiting to Spartina growth in Barataria Bay. In the highly turbid bays of the Texas coast, light may be as much a limiting factor as inorganic nutrients (Armstrong and Hinson, 1973).

The average levels of inorganic nitrogen in Corpus Christi Bay are less than those in the main part of Galveston Bay, in Trinity Bay, the portion of Galveston Bay receiving the Trinity River discharge, or in San Antonio Bay. However, the nutrient levels are about the same as the East Bay and West Bay portions of Galveston Bay which are relatively little affected by rivers and discharges.

The nitrogen in marine systems is recycled rather rapidly, inorganic nitrate or ammonia is taken up by phytoplankton which in turn release organic matter containing nitrogen into the water during photosynthesis. When the phytoplankton are consumed by filter feeders and the filter feeders are consumed or die, both dissolved and particulate organic matter are released. The dissolved and particulate organic matter is decomposed by microorganisms thereby releasing inorganic nitrogen to maintain a cycle. The level of dissolved organic nitrogen may be used as an indicator of the nitrogen available for productivity.

The nutrients required to support the day to day productivity of the bay come mainly from regeneration where the decomposition of organic matter by microorganism releases the nutrients at a relatively rapid rate. This is shown by the calculation of carbon turnover time equal to between 5 and 18 days (Table 6). The gross productivity within the Corpus Christi Bay Planktonic biotope of 22.3 pounds of carbon per acre per day (Table 3) implies a nitrogen requirement of about 3.9 pounds of nitrogen per acre per day or 1432 pounds per year based on the usually accepted average atomic ratio of C:N:P = 106:16:1. The average inorganic nitrogen concentration in Corpus Christi Bay is about 0.18 ppm-N or 3.7 pounds per acre assuming an average water depth of 7.6 feet. The turnover time is therefore 3.7/3.9 = 0.95 days which is substantially faster than the carbon turnover time. It should be emphasized that the above figures apply only to the planktonic productivity; production in grassflats and algal mats depends on nutrients recycled within the sediments which we have not evaluated for Galveston Bay at this time but do have data for Corpus Christi Bay (Table 3).

The cycling of nutrients within the bay is not completely efficient, there are losses to the sediment, to the Gulf of Mexico, and by the harvesting and migration of fish and shrimp. These losses are replaced by various sources of nutrients.

The following sources of nutrients are believed to be significant for Texas bays: 1) river flows, 2) direct runoff, 3) precipitation, 4) release from sediments, 5) fixation by microorganisms, 6) municipal

Table 6. Carbon and Nitrogen Turnover Times

		Corpus Christi	San Antonio	Galveston
Gross Productivity[a]	gm C/m^2-dy	2.52	1.0	5.87
equivalent N	gm N/m^2-dy	0.44	0.17	1.0
TOC 72-73 (b)	gm C/m^3	19.8		35.8
68 (c)	"	5.0		
60-62 (d)	"	19.0	16.4	8.7
TOC standing crop				
high estimate	gm C/m^2	45.5	21.3	85.9
low estimate	"	11.5		20.9
Turnover time C				
high estimate	days	18	21	14.6
low estimate	days	4.6		3.6
Inorganic Nitrogen				
high estimate	gm N/m^3	0.18	0.61	0.44
low estimate	"	0.16	0.28	
Standing Crop N				
high estimate	gm N/m^2	0.43	0.8	1.0
low estimate	"	0.38	0.36	
Turnover time N				
high estimate	days	0.98	4.7	1.0
low estimate	"	0.86	2.1	

(a) see Table 2
(b) CC data from TWDB, Galveston form GBP
(c) Reimers, 1968 dissertation
(d) Wilson, 1963 dissertation

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Table 9

Summary of nutrient data from Galveston Bay May 10,74 WBB

-period searched is 1968-1972 , averages are weighted towards the earlier stations because many were dropped during later parts of the study.

Form		Trinity Bay	West Bay	East Bay	Main Galv.
Organic N - diss ppm-N	mean	0.964	0.599	0.759	0.801
	max	5.46	3.00	4.20	5.20
	std. mdev.	0.58	0.40	0.50	0.45
Nitrate N ppm-N	mean	0.283	0.106	0.112	0.178
	max	1.50	0.80	0.40	7.80
	s.d.	0.28	0.10	0.071	0.29
Nitrite N ppm-N	mean	0.035	0.011	0.012	0.11
	max	0.64	0.13	0.080	7.10
	s.d.	0.061	0.013	0.014	0.44
Ammonia N ppm-N	mean	0.071	0.014	0.033	0.151
	max	3.50	0.70	1.30	5.30
	s.d.	0.28	0.060	0.148	0.415
Total inorganic N - ppm-N		0.389	0.131	0.157	0.439
Total inorg. + org N ppm-N		1.533	0.730	0.916	1.240
Total P ppm-P	mean	0.486	0.178	0.274	0.549
	max	2.00	1.70	0.90	4.20
	std.d	0.26	0.16	0.15	0.43

Stations for Trinity 24,25,26,27,38,39,42
West Bay 12,13,14
East Bay 29,30,40
Main Galv. 15,16,17,18,19,20,21,22,23,28,41,2,3,4,5

and industrial discharges. In the following sections we will attempt to evaluate these sources.

Fairly good measurements of river flow and nutrient concentrations are available for Texas bays, although in many cases the ungauged flow is significant. Smith (1973) summarized the gauged flows of nutrients into four Texas estuarine systems, including Corpus Christi and San Antonio bays but excluding flows associated with hurricanes. Armstrong and Hinson (1973) have summarized gauged flows for Galveston Bay. Both of these summaries are based on U.S.G.S. streamflow monitoring stations. The year to year variation is quite substantial, because of climatic fluctuations and long range changes in the drainage areas. In proportion to its volume, Corpus Christi Bay received much less river flow than the other two bays, and correspondingly less nutrient input.

Direct ungauged runoff is more difficult to estimate, the Texas Water Plan (TWDB, 1968) gives estimates of 0.03 million acre-feet per year for Corpus Christi mainly from Oso Creek (4.3% of total input), 0.2 for San Antonio (13% of total), and 2.1 from adjacent coastal basins for Galveston Bay (20% of total runoff). Apparently the effect of local runoff is small for Corpus Christi as far as nutrient and fresh water additions are concerned.

The significance of nutrients in rainfall is well known for many environments, particularly as a source of inorganic nitrogen, however, we have not found any previous evaluation of this source for Texas estuaries and must rely on extrapolation of measurements made in other environments. Table 10 gives a summary of some of the literature on nitrogen in precipitation.

Table 10 Nitrogen from precipitation

Environment	Reference	Mean Nitrogen Content in mg-N/liter rain water NH_3-N	NO_3-N
Maritime, N. Europe	Vaccaro (1965)	0.31	0.056
Continental USA	"	0.32	0.52
Oceanic, Bermuda	"	0.069	--
Central Florida	Brezonik (1972)	0.13	0.065

Information from conversations with several soil chemists at Texas A&M suggested estimates of precipitation input in coastal areas ranging from 3 to 10 pounds of nitrogen per acre per year; 6 pounds per acre per year with a 45 inch rainfall corresponds with a concentration of 0.58 mg-N/liter. Brezonik (1972) gives an average of 0.58 gm-N/square meter per year for rainfall plus dustfall for Florida lakes; this corresponds to about 5 pounds per acre per year. In addition to the inorganic forms of nitrogen, there can be substantial input of organic nitrogen in rainfall. Edmisten (1970) reports measurements of total nitrogen, both organic and inorganic, in rainfall in Puerto Rico of 0.46 mg-N/liter. A value intermediate between continental and maritime averages seems appropriate for our coastal zone. We have decided to evaluate the importance of precipitation on the basis of 0.4 mg-N per liter. For Texas Bay areas of 1.5 million acres of water, this represents a significant natural source of nutrients.

Release from Sediments

A certain fraction of the organic matter produced within the bay drops to the bottom where it is available to benthic organisms including microorganisms, resuspended by wave action or dredging, or lost from the system in a permanent sedimentary deposit. The recycling of nitrogen from this organic matter is hard to evaluate, but it is probably very substantial. It is instructive to calculate the amount of nitrogen within the top centimeter of sediment. Assuming a specific gravity of the sediment of 1.3, and a 50% water content (Shepard & Moore, 1955) and an organic nitrogen content of 0.043% (Jones, 1960), there are 2.8 grams of nitrogen per square meter in a 1.0 cm layer. This corresponds to 25 pounds per acre which is roughly 6 times the amount of inorganic nitrogen in the water column.

Nitrogen gas can be fixed by blue-green algae and by bacteria. However, the amount of information available on this source in estuaries is quite small. Patriquin and Knowles (1972) have shown that nitrogen fixation in the rhizosphere of marine grasses is sufficient to account for the nitrogen requirements of these plants. Brooks et al. (1971) detected nitrogen fixation in the upper 2 - 5 cm of the sediments of the Waccasassa (Fla.) estuary amounting to the equivalent of 3.3 pounds of nitrogen per acre per year. The fraction of this nitrogen which is released to the water column is unknown. Nitrogen fixation within the water column was detected only once out of four experiments in the Waccasassa, and then at a low rate.

Estimates of nitrogen input from industrial and domestic sewage discharges were provided by the Water Needs and Residuals Task Force for Corpus Christi Bay. San Antonio Bay has relatively little industry or domestic discharge. No estimates were found for this source, but it is believed to be small. Two estimates for Galveston Bay are available. One by Armstrong and Hinson (1973) is based on population, assuming a certain level of treatment, the other estimate is being prepared in conjunction with the Galveston Bay Project by the Texas Water Quality Board. This estimate is based on a detailed analysis of all sources and is probably the most accurate.

Summaries of these nitrogen sources are shown in Tables 11 and 12 in terms of thousands of pounds of nitrogen per year, pounds per acre, and relative importance of each source. A number of interesting points are brought out in these tables. One point is that in both Galveston Bay and Corpus Christi Bay, industrial and domestic discharges supply a large fraction of total nitrogen input, but the per acre loading is much higher in Galveston Bay. Among the natural sources, rainfall is a greater source of nitrogen than river flow in Corpus Christi Bay, but it is relatively small in San Antonio and Galveston Bays.

Nutrient Losses

Nutrients may be lost from the bay system by the following processes: 1) harvest of organisms, 2) sedimentation, 3) outflow to the Gulf of Mexico, 4) mixing with Gulf waters during tidal exchange, 5) denitrification (nitrogen only). We have attempted to evaluate only 1,2, and 5 in the following section, and assume that 3 and 4 are responsible for the remainder of the losses required to balance the inputs.

The losses of nutrients from the system due to commercial and sport fishing catch can be evaluated on the basis of the average composition of fish and shrimp; 0.10 lb carbon, 0.03 lbs nitrogen, and 0.002 lbs phosphorus per pound of organism (Vinogradov, 1953; Stansby and Hall, 1967). Table 13 gives the estimated rate of loss of carbon, nitrogen and phosphorus from the Corpus Christi Bay system due to

Table 11 Nitrogen Input and Freshwater Inflows

Bay System	years	Ref	Average gauged flow acre-ft/yr x 10^6	10^3 lbs N/yr	Average precipitation acre-ft/yr x 10^6	10^3 lbs N/yr[(b)] @ 0.4 ppm-N	Domestic & Industrial Discharges acre-ft/yr x 10^6	10^3 lbs N/yr
Corpus Christi	62-71	CCW			0.303	339.		
	53-71	CCW			0.312	349.		
	62-71	EMD	0.574	228.				
	53-71	EMD	0.581	567.				
	41-57	TWP	0.7					
model "wet year"	"70"	MOD	11.6	12,675[(a)]			0.90[(e)]	2,097
model "dry year"	"70"	MOD	0.096	150.8			0.90	2,097
ave 3 wet years	(c)	EMD	1.586	2,129	0.415	451.		
ave 3 dry years	(d)	EMD	0.095	112.	0.194	210.		
San Antonio	41-57	TWP	1.5		0.40	440.		
	61-71	EMD		2,170				
Galveston	41-57	TWP	10.2		1.4	1,520		
	?-73	GBP	7.6				0.482	21,260
	?	A&H		15,103				32,493

refs CCW - Corpus Christi Int. Airport Weather Station, TWP - Texas Water Plan Texas Water Development Board, 1968. GBP - Galveston Bay Project, Texas Water Quality Board, 1974 unpublished. A&H - Armstrong & Hinson (1973), EMD - Davis (1973), MOD - Estuarine Modeling Task Force.

note a - this flow rate never occurs for more than a few weeks at a time
b - based on areas, CC = 134,000 acre, SA = 143,000, GB = 341, ref TWP
c - 1957,58,67 d - 1955, 62, 63 e - includes cooling water

Table 12 Nitrogen Inflows to Texas Bays

Bay System	Total N Input		Relative Importance of each source - %		
	10^3 lbs/yr		River	Rain	Ind.+ Dom.
Corpus ave 62-71	2,664	19.9	8.5%	12.7%	78.7%
ave 3 wet years (a)	4,677	34.9	45.5	9.6	44.8
ave 3 dry years (b)	2,419	18.0	4.6	8.6	86.7
S. Antonio ave 61-71	2,610	18.3	83.1%	16.9%	0 (c)
Galveston recent? (d)	49,116	144.	30.7	3.1	66.1
?-74 (e)	37,883	111.	39.8	4.0	56.1

a - using 1957, 1958, 1967 with "70" model Industrial & Domestic
b - using 1955, 1962, 1963 with "70" model Industrial & Domestic
c - no specific information available, assumed to be very low
d - Armstrong & Hinton (1973)
e - Galveston Bay Project, unpublished

TABLE 13 Carbon, nitrogen and phosphorus equivilences of the average commercial catch and estimated sportfishing catch of all organisms in Corpus Christi Bay.

Units	Carbon	Nitrogen	Phosphorus	Total Weight
pounds/day	197.4	59.2	4.0	1,974
pounds/year	72,120	21,600	1,442	721,200[2]
pounds/acre-year[1]	0.63	0.19	0.013	6.27

[1]based on an area of 115,000 acres

[2]assumes sports catch equals commercial catch of fin fish, Table IV A-4.

TABLE 14 Carbon nitrogen and phosphorus removed per acre per year from three Texas Bays.

Bay System	Area acres	Total Catch	Pounds per Acre per Year Carbon	Nitrogen	Phosphorus
Corpus Christi	115,000	6.27	0.63	0.19	0.013
San Antonio	143,000	15.4	1.54	0.46	0.031
Galveston	333,000	28.5	2.85	0.86	0.057

commercial fishing and sport fishing. Table 14 gives the same information in terms of pounds per acre per year for Galveston Bay and San Antonio Bay in comparison with Corpus Christi Bay, however, no estimate for sport fishing has been included in the catch for San Antonio or Galveston Bay.

Sedimentation rates in Texas estuaries have been evaluated by Sheppard (1953) by comparison of surveys taken in the late 1800's with recent surveys. Table 15 gives the sedimentation rates determined, with and without allowance for subsidence at 1.8 feet per century. Using the sediment specific gravity of 1.3 with a water content of 50% given by Shepard & Moore (1955) with an organic nitrogen content of 0.043% (Jones, 1960), we can calculate the nitrogen loss rate shown in the Table. These should be regarded as very approximate since we do not have detailed sediment analysis for each bay.

Table 15 Sedimentation rates in Texas Bays deduced from historical depth changes (Shepard & Moore, 1953).

Rate	Units	Corpus	San Antonio	Galveston
Depth change	Ft/100 yr	1.56	1.23	1.44
Depth change + subsidence	Ft/100 yr	3.36	3.03	3.24
Nitrogen loss - min	lbs-N/acre-yr	11.9	9.25	11.0
- max		25.5	23.0	25.0

Denitrification, the reduction of nitrate to N_2 gas, is known to be an important nitrogen sink in lakes, but its importance in the marine environment is less well defined (Brezonik, 1972). Denitrification can only occur under anaerobic or very low oxygen conditions, and these conditions only occur in the sediments and in the innermost harbor waters in Corpus Christi Bay. We have been unable to find information on denitrification in estuarine sediments, but the rates given by Brezonik for lake sediments and anoxic waters range from 8 to 330 micrograms N per liter per day. Denitrification in sediments can only occur near the interface between oxic and anoxic conditions where nitrate can diffuse into the sediment. Postulating a 0.5 cm layer for these conditions, 100 micrograms N per liter per day corresponds to 1.6 pounds of nitrogen per acre per year. This is the same order of magnitude as nitrogen fixation, and since both processes are equally hard to determine, we have left them out of the final nutrient budget summary.

Nitrogen Budget Summary

Table 16 summarizes the sources, sinks and standing crops of nitrogen in Corpus Christi, San Antonio and Galveston Bays, as they have been discussed in this chapter. It is apparent that the higher fertilization rate in Galveston Bay is associated with a higher productivity and higher standing crop of inorganic nitrogen nutrients. The loss of nitrogen to the sediments could balance nitrogen inflows in Corpus Christi and San Antonio Bays, but not Galveston Bay.

If industrial and domestic sewage treatment plant discharges to Corpus Christi Bay were stopped, or their nitrogen content eliminated, the nitrogen inflow would drop to an average of 4.3 pounds per acre per year. The low inflow rate would soon cause a reduction in productivity, but the magnitude of this reduction cannot be determined at this time.

IMPLICATIONS FOR MANAGEMENT OF BAYS AND ESTUARIES

Man's activities have a strong influence on the nutrient balance in Corpus Christi Bay, but a reduction of this influence would probably

TABLE 16 Sources, sinks and standing crops for Nitrogen in Three Texas Bays.

		Corpus Christi	San Antonio	Galveston
Inflows	lbs-N/acre-yr	19.9	18.3	111.
Harvest	lbs-N/acre-yr	0.19	0.46	0.86
as a fraction of source		0.95%	2.5%	0.77%
Gross production and respiration (a)	$\frac{\text{lbs-N}}{\text{acre-yr}}$	1054	424	2490
Loss in sediments - min	$\frac{\text{lbs-N}}{\text{acre-yr}}$	11.9	9.25	11.0
- max		25.5	23.0	25.0
Standing Crop Inorganic Nitrogen	$\frac{\text{lbs-N}}{\text{acre-}}$	3.72	3.05	9.57

(a) planktonic biotope only

mean reduction of productivity. At the present loading rates, Corpus Christi Bay does not appear to be exhibiting any symptoms of eutrophication except in localized areas such as back half of the inner harbor. There appears to be no need for reduction of nutrients in present effluents, and in fact, a reduction might be detrimental. River flow does not contribute a significant amount of nitrogen to the bay in average years, therefore, the main justification for maintaining river flows to the bay must be related to maintenance of a desirable salinity regime, or the addition of trace nutrients.

The first symptoms of excessive nutrient levels are the appearance of nuisance algal blooms which would be unsightly, alter the food chain, and possibly lead to low oxygen levels in the bay during unusually calm weather. Galveston Bay, which exhibits nitrogen nutrient levels about twice those of Corpus Christi Bay, has definitely higher productivity, but does not (yet) exhibit nuisance algal blooms in the main portions of the bay. Therefore, we tentatively propose that the average inorganic nitrogen levels in Galveston Bay, 0.44 ppm-N, should be adopted as maximum nitrogen standard for the planktonic biotope of Corpus Christi Bay. The standard for inorganic nitrogen must be supplemented with one for total nitrogen because at the peak of an algal bloom, there is very little nutrient left in the inorganic form. Again using the Galveston Bay data, we suggest that a maximum total nitrogen level of 1.4 ppm-N should be adopted as a tentative standard.

During this interpretation we examined all available information in our other data files for the past several years. You will note in Table 9 that the maximum values are considerably larger than those we recommend. An analysis of all data indicated that these high values were due to a relatively few samples and therefore the average or mean was weighed toward the lower part of the range. At this time we are in the process of evaluating this series of high peaks. It is possible that they represent an analogy to the practices of farm fertilizing where a slug is provided at periodic intervals. Nature may be supplementing this practice in our estuaries through bursts of rainfall that coincide with periods of dryness. Thus the nitrogen entering the bays at those times would give the high values observed. We do not know how to interpret this phenomenon at this time.

Therefore one must be very cautious in interpretation of nitrogen allowable values and suggest the above allowable numbers as tentative, subject to change as our knowledge of the dynamics of bay fertilization becomes better known.

As an index of nuisance algal blooms, a standard for chlorophyll a has been suggested for the Chesapeake Bay by Clark, Donnelly and Villa (1973). The limit they propose, which is based on local algal populations, is 0.040 mg chlorophyll a per liter. To maintain this level, they propose inorganic nitrogen limits of 0.80 ppm-N and a total phosphorus limit of 0.12 ppm-PO4 (0.04 ppm-P). The Chesapeake nutrient data, however, shows much less organic nitrogen than is present in Texas bays, indicating that the dynamics of the nutrient cycles are different. At the present time, there is not enough chlorophyll a data available to suggest similar standards for Corpus Christi Bay.

Trace Elements and Toxic Compounds

Our approach to the subject of significance of trace elements in Texas bays, which coincides with that of the E.P.A., is to evaluate the existence and responses of estuarine populations in the face of natural levels of trace elements and toxic compounds. This yields _in situ_ information concerning adverse effects. Where no adverse effects can be determined, trace element concentrations could be interpreted as being within natural tolerance levels. Controls to prevent exceeding safe levels such as waste discharge permits and changes in allowable discharges may become even more important in maintaining safe levels.

We have made use of two concepts which we feel have been lately overlooked. First, trace elements at low concentrations are essential to all life forms. Examples are dietary requirements of Zinc and Manganese in chickens, Copper in pigs, and Cobalt, Magnesium, Iron and Selenium for nearly all organisms. Second, nearly all trace materials are present in sea water, thus exposing marine organisms to far more than is normally encountered by terrestrial or aquatic organisms. The behavior of these materials in sea water differs from their behavior in the laboratory due to chelation, adsorption and other effects caused by the presence of so many ionic forms as well as dissolved organic matter and sedimentary particles.

The blanket form of the FWPCA water quality criteria published in 1968 (FWPCA, 1968) led quickly to recognition that in some areas, naturally occurring background concentrations of some of the materials were in excess of the maximum allowable levels (Table 19). The National Academy of Sciences and National Academy of Engineering (NAS-NAE) were then given the task of recommending criteria which could cope with such environmental variations. These recommendations have been delivered to the Environmental Protection Agency (NAS-NAE, 1974, in press).

The proposed standards consist of three kinds of criteria. They are the application factors for various materials; maximum aqueous natural levels of trace elements and toxic compounds. This yields *in situ* information concerning adverse effects. Where no adverse effects can be determined, trace element concentrations could be interpreted as being within natural tolerance levels. Controls to prevent exceeding safe levels such as waste discharge permits and changes in allowable discharges may become even more important in maintaining safe levels.

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The proposed standards consist of three kinds of criteria. They are the application factors for various materials; maximum aqueous concentration levels, and maximum concentration levels in prey organisms for the top level predatory birds and mammals.

The application factor is designed to control the concentration of waste discharges by reducing their concentration to some designated fraction below a 96 hour lethal level. The instructions for ascertaining the 96 hr lethal levels include use of sensitive indigenous species and use of the local receiving waters as the test medium. This, it is hoped, will allow for adjustment of water quality criteria with regard to high background levels of various materials by integrating these background effects into the toxicity experiments. Finally, seasonal variation must be accounted for. The application factors for toxic inorganic materials are shown together with relative pollution menace in Table 17. The general application factor of 0.01 for toxic organics has been applied to 96 hr TLMSO data for local organisms and the maximum levels permissible for this area are shown in Table 18. Table 19 is a list of abundances of all elements as compiled from separate literature list cited.

The aqueous concentration levels specifically recommended by NAS-NAE are limited to the toxic inorganics. Table 20 shows the hazard and minimum risk levels designated by NAS-NAE. The next column shows levels of some of these materials found in the open bay environment of Corpus Christi Bay. Of these only Boron and Iron sometimes exceed "hazardous" levels. In the restricted waters of the Corpus Christi and LaQuinta Ship Channels, levels of Zinc and Cadmium may exceed the "hazard levels" by four to seven-fold (Holmes, et al., 1974; Texas Water Quality Board, unpub. data). The fourth column shows the range of these materials in sea water. The final column constitutes this

Table 17 Application factor and pollution category for toxic inorganic materials.[1]

SUBSTANCE	APPLICATION[2] FACTOR	POLLUTION[3] CATEGORY
Aluminum	0.01	4c
Amonia	0.1	4c
Antimony	0.01	4c
Arsenic	0.01	2c
Barium	0.05	4c
Beryllium	0.01	4c
Boron	0.1	4c
Bromine	--	4c
Cadmium	0.01	2c
Chlorine(Gas)	0.1	4c
Copper	0.01	4c
Cyanides	0.1	3c
Fluoride	0.1	4c
Iron	--	4c
Lead	0.01	1a
Manganese	0.02	4c
Mercury	--	1b
Molybdenum	0.02	4c
Phosphorus(demental)	0.01	--
Selenium	0.01	3c
Silver	0.05	3c
Sulfides(pH 6.5-8.5)	0.1	2c
Thallium	0.05	3c
Uranium	0.01	3c
Vanaduim	0.05	4a
Zinc	0.01	3c

[1]NAS-NAE, 1974.

[2]Fraction of TLM50 for most sensitive indigenous organism, tested in local wa[illegible]

[3][illegible]

Table 18 Maximum allowable environmental concentrations of selected pesticides.

SUBSTANCE	MAXIMUM CONCENTRATION ALLOWABLE[2]	TEST ORGANISM[1]
Heptachlor	.08 ppb	Crangon septemspinosa
Aldrin	.08 ppb	Crangon septemspinosa
Dieldrin	.07 ppb	Crangon septemspinosa
Lindane	.05 ppb	Crangon septemspinosa
		Pagurus longicarpus
Methoxychlor	.04 ppb	Crangon septemspinosa
Endrin	.02 ppb	Crangon septemspinosa
		Pagurus longicarpus
p, p'-DDT	.006 ppb	Crangon septemspinosa
Delnav	.38 ppb	Crangon septemspinosa
Malathion	.33 ppb	Crangon septemspinosa
Phosdrin	.11 ppb	Crangon septemspinosa
DDVP	.04 ppb	Crangon septemspinosa
Methyl parathion	.02 ppb	Crangon septemspinosa

[1]Eisler, 1969. Table 20 , reference No. 4.

[2]Application factor = 0.01 of 96 hr. TLM 50 for test organism shown.

TABLE 19

Comparative Values of Elements in the Environment*

	Element	Seawater Range (mg/l)	Earth Crust Average (ppm)	Marine Organisms Range (ppm)	Land Organisms Range (ppm)
H	Hydrogen	108,000	1,400	41,000 - 52,000	55,000 - 70,000
He	Helium	.0000069 - .000005	.008	1 - 5	.02 - .1
Li	Lithium	.18 - .1	20	.001	.1 - .0003
Be	Beryllium	.0000005 - .0000006	2.8	20 - 120	50 - .5
B	Boron	4.7 - 4.6	10	345 - 100,000	280,000 - 465,000
C	Carbon	28	200	15,000 - 75,000	30,000 - 100,000
N	Nitrogen	0.5	510	400,000 - 470,000	186,000 - 410,000
O	Oxygen	857,000	464,000	2 - 4.5	.5 - 1,500
F	Fluorine	1.4 - 1.3	625		
Ne	Neon	.00014	.005	4,000 - 48,000	4,000 - 1,200
Na	Sodium	10,769 - 10,293	23,600	5,000 - 5,200	1,000 - 3,200
Mg	Magnesium	1,350 - 1,262	23,300	10 - 60	.5 - 4,000
Al	Aluminum	1.9 - .01	82,000	70 - 20,000	120 - 6,000
Si	Silicon	4 - .02	281,500	3,500 - 18,000	2,300 - 44,000
P	Phosphorus	.1 - .07	1,050	5,000 - 19,000	3,400 - 5,000
S	Sulphur	901 - 884	260	47,000 - 90,000	2,000 - 2,800
Cl	Chlorine	19,353 - 18,550	130		.75 (Mammalian Blood)
Ar	Argon	.6	3.5	5,000 - 52,000	7,400 - 1,400
K	Potassium	387 - 376	20,900	1,500 - 300,000	200 - 260,000
Ca	Calcium	408 - 389	41,500		.008 - .00006
Sc	Scandium	.00004 - .000004	22	.2 - 80	.2 - 1
Ti	Titanium	.00002 - .001	5,700	.14 - 2	1.6 - .15
V	Vanadium	.002 - .0003	135	1 - .2 (108)	.23 - .075
Cr	Chromium	.00025 - .00005	100	1 - 60	.2 - 630
Mn	Manganese	.01 - .002	950	400 - 700	140 - 160
Fe	Iron	.15 - .001 (10^{-9})	56,300	.5 - 5	.5 - .03
Co	Cobalt	.0001 - .0007	25	.4 - 25	.8 - 3
Ni	Nickel	.006 - .0001	75	4 - 50	2.4 - 14
Cu	Copper	.01 - .0005	55	6 - 1500	100 - 160
Zn	Zinc	.021 - .005	70	.5	.006 - .06
Ga	Gallium	.000007 - .0005	15	.3	
Ge	Germanium	.00007 - .00006	5.4	.3 - 150	.2
As	Arsenic	.03 - .0003	1.8	.8	.2 - 1.7
Se	Selenium	.006 - .00009	.05	60 - 1,000	6 - 15
Br	Bromine	66 - 65	2.5		
Kr	Krypton	.0025 - .0003	.0001	20 - 7.4	17 - 20
Rb	Rubidium	.2 - .12	90	20 - 1400	14 - 26
Sr	Strontium	13 - 8.1	375	.1 - .2	.04 - .6
Y	Yttrium	.0003	33	.1 - 20	.3 - .64
Zr	Zirconium	2.2 X 10^{-5}	165	.001 - 300	.3
Nb	Niobium	.00002 - .00001	20	2.5 - .45	.9 - .2
Mo	Molybdenum	.01 - .0003	1.5		

Pd	Palladium		.01		.002
Ag	Silver	.0003 - .00004	.07	11 - .25	.8 - .006
Cd	Cadmium	.00001 - .00011	.2	3 - .15	.6 - .5
In	Indium	< .02	.05 - 1		.016
Sn	Tin	.003 - .0008	2	.2 - 20	.15 - .3
Sb	Antimony	.00033 - .0005	.2	.2	.006 - .06
Te	Tellurium		.001 - .01		.02 - 25
I	Iodine	.06 - .05	.5	1 - 1500	.42 - .43
Xe	Xenon	.000052 - .0001	.00003		
Cs	Cesium	.002 - .00005	2	.07	.2 - .064
Ba	Barium	.06 - .01	425	30 - .2	(4000) 14 - .75
La	Lanthanum	.0003 - 1.2 X 10^{-5}	30	.1 - 10	.0001 - .085
Ce	Cerium	.0004 - 5.2 X 10^{-6}	60		320 - .03
Pr	Praseodymium	2.6 X 10^{-6}	8.2	.5 - 5	46
Nd	Neodymium	9.2 X 10^{-6}	28	.5 - 5	460
Pm	Promethium				
Sm	Samarium	1.7 X 10^{-6}	6	.04 - .08	.01 - .0055
Eu	Europium	4.6 X 10^{-7}	1.2	.06 - .01	.021 - .00012
Gd	Gadolinium	2.4 X 10^{-6}	5.4	.06	70
Tb	Terbium		.9	.006 - .01	.0015 - .0004
Dy	Dysprosium	2.9 X 10^{-6}	3		.02 - .01
Ho	Holmium	8.8 X 10^{-7}	1.2	.005 - .01	.5 - 16
Er	Erbium	2.4 X 10^{-6}	2.8	.04 - .02	2 - 46
Tm	Thulium	5.2 X 10^{-7}	.5		.0015 - .00004
Yb	Ytterbium	2.0 X 10^{-6}	3.4	.02	.00012 - .0015
Lu	Lutetium	4.8 X 10^{-7}	.5	.003	4.5 - .00012
Hf	Hafnium	8 X 10^{-6}	3.2	< .4	.04 - .01
Ta	Tantalum	2.5 X 10^{-6}	2	410	
W	Tungsten	.00012	1.5	.0005 - .05	.005 - .07
Re	Rhenium		.005 - .001	.014 - .0005	
Os	Osmium		.0015 - .005		
Ir	Iridium		.001		.00002 - .02
Pt	Platinum		.005 - .01		.002
Au	Gold	.000015 - .000004	.004	.012 - .0003	.04 - .00023
Hg	Mercury	.0003 - .00003	.08	.03	.046 - .015
Tl	Thallium	< .00001	.5		.4
Pb	Lead	.006 - .00003	13	.5 - 8.4	2 - 2.7
Bi	Bismuth	.000017 - .0002	.17	.3 - 0.4	.06 - .004
Po	Polonium		2 X 10^{-10}	15 - 17**	.1 - 600**
At	Astatine				
Rn	Radon	6 X 10^{16} - 0.6 X 10^{-15}	4 X 10^{-13}		
Fr	Francium				
Ra	Radium	3 X 10^{10} - 2 X 10^{-11}	9 X 10^{-7}	.7 - 15 X 10^{-8}	10^{-9} - 7 X 10^{-9}
Ac	Actinium		5.5 X 10^{-10}		
Th	Thorium	<.0005 - .00005	8.3	.003 - .03	.003 - .1
Pa	Protactinium	2.4 X 10^{-11} - 2.0 X 10^{-9}	1.4 X 10^{-6}		
U	Uranium	.015 - .00015	2.7	.004 - 3.2	.038 - .013
Np	Neptunium				
Pu	Plutonium				.07 - 6.8**
Am	Americium				
Cm	Curium		.0001		
Bk	Berkelium				
Cf	Californium				
Es	Einsteinium				
Fm	Fermium				
Md	Mendelevium				

* Taken from various authors listed in bibliography

** Disintegrations sec.$^{-1}$ kg^{-1}

Table 20

SUBSTANCE	NAS - NAE HAZARD	NAS - NAE MINIMUM RISK	LOCAL WATER CONCENTRATIONS[1]	MEAN SEA WATER CONCENTRATIONS[2]	TASK FORCE RECOMMENDATIONS CORPUS CHRISTI BAY
Aluminum	1.5 ppm	0.2 ppm	--	0.01 - 1.9 ppm	1.5 ppm
Ammonia	0.4 ppm	0.01 ppm	0.9 - 6.0 ppm NH_4^+	--	0.2 ppm
Antimony	0.2 ppm	--	--	0.5 - 0.3 ppb	0.1 ppm
Arsenic	0.05 ppm	0.01 ppm	--	0.3 - 30 ppb	0.03 ppm
Barium	1.0 ppm	0.5 ppm	--	0.01 - 0.06 ppm	1.0
Beryllium	1.5 ppm	0.1 ppm	--	5×10^{-4} ppb	0.5
Boron	G.T. 5.0 ppm	L.T. 5.0 ppm	0.06 - 8.1 ppm	4.7 ppm	L.T. 5.0 ppm
Bromine: Br_2	L.T. 0.1 ppm	--	65 ppm Br^-	--	L.T. 0.01 ppm
BrO_3	L.T. 100 ppm	--		--	L.T. 100 ppm
Cadmium	0.01 ppm	0.2 ppb	--	0.01 - 0.1 ppb	0.001
Chlorine (Gas)	0.01 ppm	--	--	--	0.01
Copper	0.05 ppm	0.01 ppm	0.8 - 21 ppb	0.5 - 10 ppb	0.02
Cyanides	10 ppb	5 ppb	--	--	0.005
Fluoride	1.5 ppm	0.5 ppm	0.1 - 0.9 ppb	1.3 ppm	1.0
Iron	0.3 ppm	0.05 ppm	0 - 0.8 ppm	0.1 - 0.7 ppm	2.0
Lead	0.05 ppm	0.01 ppm	0 - 7 ppb	0.3 - 6 ppb	0.01
Manganese	0.1 ppm	0.02 ppm	5 - 15 ppb	2 - 10 ppb	0.05
Mercury	0.1 ppb	--	--	0.03 - 0.3 ppb	0.0003
Molybdenum	0.1 ppm	2 ppb	--	0.3 - 10 ppb	0.01

SUBSTANCE	NAS - NAE HAZARD	MINIMUM RISK	LOCAL WATER CONCENTRATIONS[1]	MEAN SEA WATER CONCENTRATIONS[2]	TASK FORCE RECOMMENDATIONS CORPUS CHRISTI BAY
Phosphorus (elemental)	1 ppb	--	--	--	0.001
Selenium	10 ppb	5 ppb	--	0.09 - 6 ppb	0.01
Silver	5 ppb	1 ppb	--	0.04 - 0.3 ppb	0.001
Sulfides	10 ppb	5 ppb	--	--	.01 open water G.T. 7' depth .1 water L.T. 7' and anearobic sed.
Thallium	0.1 ppm	0.05 ppm	--	L.T. 0.01 ppb	0.00001
Uranium	0.5 ppm	0.1 ppm	--	0.15 - 15 ppb	0.1
Vanadium	--	--	--	0.3 - 2 ppb	1.0
Zinc	0.1 ppm	0.02 ppm	6 - 60 ppb	5 - 21 ppb	0.6

References:

[1]
1. Parker, et. al., 1963.
2. Parker, 1962.
3. Hahl, et al., 1972.
4. Hahl, et. al., 1970.
5. Blakely and Kunze, 1971.
6. Holmes, et. al., 1974.

[2] Bowen, 1966; Comar and Bronner, 1962; Florin, 1960; Frieden, 1972; Goldberg, 1972; Jones, 1964; Miller, 1969; Nicol, 1967; Stansby and Hall, 1967; Vinegradov, 1953.

task force's recommendations concerning local levels of these materials. High recommended levels of sulfides take into account the prevalence of wind driven resuspension of anaerobic sediments in shallow areas of the bay thus releasing sulfides.

Since no limits for aqueous levels were described for toxic organic compounds, no recommendations are made here. However, Tables 21 and 22 are presented as reference materials concerning toxicities of various materials in marine environments. The values shown in Table 21 were the lowest lethal concentrations found regardless of time of exposure or percent kill for any of the materials. This is due to the wide diversity of methods employed in these determinations. Table 22 shows the acute dose lethal to 50 percent of the birds, mallards and quail, which were dosed with materials which they might encounter in the local environment. The rationale for ingested doses was that birds were likely to ingest such materials with their food or during preening. No firm water quality criteria can be developed at this time for such toxic organic materials.

A synopsis of this information, then reveals a lack of data in several areas. More information is needed concerning the sensitivity of organisms indigenous to Corpus Christi Bay to both organic and inorganic materials. Use of a standard method for determining such sensitivities is required. Such a method must take into account dose, time of exposure percent kill at that exposure. The 96 hr TLM50 method is recommended by this task force because of its present use in defining the proposed standards. The aqueous medium for these experiments should in all practical cases be filtered water from the bay system. There are drawbacks to this in that some materials may be antagonized in their toxicity by adsorption to suspended sedimentary particles which would

Table 21 Toxicity levels for marine and estuarine organisms endemic to the Corpus Christi Bay area.

SUBSTANCE	FISH	CRUSTACEA	PLANTS	MOLLUSCS	BIRDS[1]	REFERENCES
Heptachlor	.8 ppb	8 ppb		10 ppm	≥ 2000 ppm	48,37,39,4,8
Niacinamide				.42 ppm		27
Cu	.5 ppm		.03 ppm	.025 ppm		36,29,26,25,10,23
$CuCO_3$				.14 ppm		28
Cu sulfate				.5 ppm		28
Mirex		.01 ppb		10 ppb	> 2400 ppm	9,46
LAS detergent				.1 ppm		1,32
ABS detergent	.7 ppm			.5 ppm		1,17
DDT	1 ppm	.5 ppb	.04 ppm	.025 ppm	30 ppm	43,48,42,40,36,34,30,6,22,1,2,14
pH				7 - 9		1
Toxaphene	5 ppb		.01 ppm	.25 ppm	30.8 ppm	48,43,42,30,2
Endrin	.05 ppb	1.7 ppb		.01 ppm	.125 ppm/day	48,39,38,37,6,8,4
Aldrin	.5 ppb	.8 ppb		.1 ppb	5 ppm/day	48,43,37,39,4,6
DEF						6
Baytex				1.0 ppm	.5 ppm/day	6,48
Dibrom				.1 ppm	52.2 ppm	6,48
Fungicide w/tin				1 ppm		7
Pure streptomycin				1 ppt		19

SUBSTANCE	FISH	CRUSTACEA	PLANTS	MOLLUSCS	BIRDS[1]	REFERENCES
Commercial streptomycin				1 ppt		19
Pure aureomycin				3.2/10,000		19
Commercial terramycin				1 ppb		19
Arochlor 1254	5 ppb	1 ppb		5 ppb	2000 ppm	48,21,11,15,20
DDE					10 ppm	12
Dieldrin	.9 ppb	1 ppb		.1 ppm	2.5 ppm/day	48,43,39,37,4,13
Fluoride		52 ppm		32 ppm		18
Organic mercury compounds			1 ppb			16
Pb				.1-.2 ppm		5
Radiation				5,833 R		24
Zn				.1 ppm		29
Cd				-.1 ppm		29
Cr				.1 ppm		29
Lindane	.9 ppb	5 ppb	2.5 ppm	.5 ppm	30.1 ppm/day	48,43,42,39,37,4
Endrin		1.7 ppb		1 ppm		43,39,37,4
p,p'-DDT	4 ppb	.6 ppb		10 ppm		4,39,37
Delnav		38 ppb				4
Malathion	.027 ppm	33 ppb		25 ppm	1485 ppm	48,4,37,39
Phosdrin	.065 ppm	11 ppb		-25 ppm	4.63 ppm	48,37,4,39

Table 21 (cont.)

SUBSTANCE	FISH	CRUSTACEA	PLANTS	MOLLUSCS	BIRDS[1]	REFERENCES
Methyl parathion	5.2 ppm	2 ppb		25 ppm	10 ppm	48,4,39,37
Methoxychlor	.12 ppb	4 ppb		10 ppm		4,39,37
Sodium acid pyrophosphate	500 ppm	500 ppm		500 ppm		3
Quadrafos				3,500 ppm		3
Impermex	5000 ppm			1000 ppm		3
Sodium polyphosphate	500 ppm			500 ppm		3
Stabilite #9	500 ppm			500 ppm		3
Caustic Soda	70 ppm	70 ppm				3
Oil well cement	100 ppm			100 ppm		3
Tannex	100 ppm			90 ppm		3,33
White lime	125 ppm	125 ppm		125 ppm		3
Parathion				-1 ppm	.01 ppm/day	43,30,48
Silt				.1 ppt		31
Kaolin				.1 ppt		31
$CaCO_3$				.1 ppt		31
Biodegradeable detergent				.25 ppm		32
Aquagel				110 ppm		33,3
Turbidity				200 ppm		33
Dioxathion	.6 ppb	.038 ppm		25 ppm		37,39

Table 21 — (cont.)

SUBSTANCE	FISH	CRUSTACEA	PLANTS	MOLLUSCS	BIRDS[1]	REFERENCES
Hg				12 ppm		41
Dipterex			50 ppm	1 ppm		42,43
TEPP			300 ppm	1 ppm	3.56 ppm	48,42,43
Phenol			10 ppm	10 ppm		42,43
Dowacide A			50 ppm	1 ppm		42,43
Orthodichlorobenzene			7.6 ppm	10 ppm		42,43
Chloronitropropane			8 ppm			42
PVP-iodine			20 ppm			42
Sevin			.1 ppm	1 ppm	125 ppm	48,42,43
Nabam			.1 ppm	-.5 ppm	> 2560 ppm	48,42,43
Lignasan			.6 ppb			42
Fenuron			.29 ppm	5 ppm		42,43
Neburon			.04 ppm	2.4 ppm		42,43
Monuron			1 ppb	5 ppm		42
Diuron			.02 ppb	1 ppm	> 2000 ppm	48,42,43
Dowacide G				.25 ppm		43
Roccal				.2 ppm		43
Nemagon				.25 ppm	66.8 ppm	43,48
Choramphenicol				10 ppm		43
Delrad				.05 ppm		43

SUBSTANCE	FISH	CRUSTACEA	PLANTS	MOLLUSCS	BIRDS[1]	REFERENCES
Sulmet				10 ppm		43
Trichlorobenzene				10 ppm		43
Acetone				100 ppm		43
Allyl Alcohol				.25 ppm		43
Niagara compound N-3452				1 ppm		43
Niagara compound N-3514				-1 ppm		43
Dicapthon				1 ppm		43
Guthion				.5 ppm	8.75 ppm/day	43,48
Zineb					> 2000 ppm	48
Cationic surfactants				.3 ppm		44
Anionic surfactants				1.15 ppm		44
Nonionic surfactants				2.33 ppm		

[1]These values are dosages either ingested, injected or assimilated from topical application. Units are derived from milligrams of dose per kilogram of body weight. The symbol ≫ equals "much greater than".

Table 22 Toxicity levels for birds endemic to the Corpus Christi Bay area.[1]

SUBSTANCE	LD 50 DOSE[2]
Abate	2.5 ppm/day
Accothion	10 ppm/day
Actidione	50 ppm
Agrox	> 2000 ppm
Akton	> 2000 ppm
Allethrin	>> 2000 ppm
Aminotriazole	> 2000 ppm
Atrazine	> 2000 ppm
Azodrin	.25 ppm/day
Balan	> 2000 ppm
Bay 37289	5.66 ppm
Baygon	6 ppm/day
Bidrin	.250 ppm/day
Bordeaux mixture	> 2000 ppm
Botran	> 2000 ppm
Casoron	> 2000 ppm
Ceresan L	30 ppm/day
Ceresan M	> 2262 ppm
Chlordane	1200 ppm
Ciodrin	790 ppm
CIPC	> 2000 ppm
Co-Ral	29.8 ppm
Cotoran	> 2000 ppm
2, 4-D	>> 1000 ppm
Dasanit	.749 ppm
Diazinon	3.4 ppm
Diesel oil #1	20 ppm
Dimethoate	6 ppm/day
Diquat	564 ppm
Disyston	4.24 ppm
D.M. 7537	< 2.5 ppm
Dursban	25 ppm
Dyrene	> 2000 ppm
Elgetol	22.7 ppm
EPN	3.08 ppm
Famophos	9.87 ppm
Folpet	> 2000 ppm
Furadan	1 ppm
Gardona	>> 2200 ppm
GC 6506	1.12 ppm
Gophacide	24 ppm
GS 13005	23.6 ppm
Imidan	96 ppm
IPC-400	> 2000 ppm
Landrin	16.8 ppm
Lannate	7.5 ppm/day
Matacil	22.5 ppm
Mema RM	1059 ppm
Mestranol	> 1000 ppm
Meta-systox-R	53.9 ppm
Mobam	40 ppm/day
Nicotine sulphate	6 ppm
Norbormide	> 3000 ppm
Nucleopolyhedral virus	> 361 ppm
OMPA	36.3 ppm
Panogen	56.1 ppm
Phosphamidon	3.05 ppm
Phygon	> 2000 ppm
Pyrethrum	> 10,000 ppm
Rotenone	> 2000 ppm
SD 7727	> 2000 ppm
SD 11831	100 ppm/day
SD 15418	150 ppm
Silvex	500 ppm
Sodium arsenite	323 ppm
Sodium monofluoro-acetate	.5 ppm/day
Strychnine	2.9 ppm
Sulfoxide	> 2000 ppm
Supona	85.5 ppm
Systox	2.5 ppm/day
Telodrin	4.15 ppm
Tenoran	2000 ppm
TEPA	8.54 ppm
Thimet	.09 ppm
Thiodan	33 ppm
Thiram	> 2800 ppm
Thuricide	>> 2000 ppm
Tordon	> 2000 ppm
Treflan	> 2000 ppm
Trithion	121 ppm
Zectran	1.25 ppm/day
Zectran (acylated)	> 2000 ppm

[1] Tucker and Crabtree, 1970.
[2] These valuse are dosages either ingested, injected or assimilated from topical application. Units are derived from milligrams of dose per kilogram body weigh

be removed by filtering. This would lead to erroneously high 96 hr TLM50 values in such cases. A final information need is the concentration of the various toxic organic materials in the local waters.

References
Nutrient Cycles

Armstrong, N.E. and M.O. Hinson. 1973. Galveston Bay ecosystem freshwater requirements and photoplankton productivity. In: C.H. Oppenheimer (ed.) Toxicity studies of Galveston Bay project. Report to the Texas Water Quality Board. IAC (72-73) 183. p. II-1-II-98.

Beldon Associates. 1960. The saltwater fish harvest of Texas sportsmen, 1960. Second state-wide survey for the Texas Game and Fish Commission. Dallas, Tx.

Brezonik, P.L. 1972. Nitrogen: sources and transformations in natural waters. In: H.E. Allen and J.R. Kramer (eds.) Nutrients in natural waters. Wiley. New York. 457 p.

Brooks, R.H., et al. 1971. Nitrogen fixation in an estuarine environment, the Waccasassa on the Florida Gulf coast. Limnol. Oceanogr. 16: 701-710.

Burkholder, P.R., A. Repak and J. Sibert. 1965. Studies on some Long Island Sound littoral communities of microorganisms and their primary productivity. Bull. Torrey Bot. Club. 92:378-402.

Cechova, I. and E.M. Davis. 1973. Trend surface analysis and seasonal distribution patterns of primary nutrients and chlorophyll in unstratified Gulf Coast estuaries. Water Resources Research. 9:1543-54.

Clark, L.J., D.K. Donnelly and O. Villa. 1973. Nutrient enrichment and control requirements in the upper Chesapeake Bay -- summary and conclusions. E.P.A. Annapolis Field Office. Tech. Rpt. 56. E.P.A. 903/9-73-002-a. 24 p.

Copeland, B.J. 1965. Evidence for regulation of community metabolism in a marine ecosystem. Ecology. 46(4):563-564.

__________ and R.S. Jones. 1965. Community metabolism in some hypersaline waters. Tex. J. Sci. 17(2):188-205.

Corliss, J. and L. Trent. 1971. Comparison of phytoplankton production between natural and altered areas in West Bay, Texas. Fish. Bull. 69(4):829-832.

Cox, G.W. 1967. Laboratory manual of general ecology. Wm. C. Brown. Dubuque, Iowa. 165 p.

Davis, E.M. 1971. Development of methodology for evaluation and prediction of this limnological aspects of Matagorda and San Antonio Bays. Report to the Texas Water Development Board. IAC(70-71) 467.

________ 1973. Assessment of the primary ecological interactions in four Texas estuarine systems. Report to the Texas Water Development Board. IAC(72-73) 909.

Edmisten, J. 1970. Preliminary studies of the nitrogen budget of a tropical rain forest. In: H.T. Odum (ed.) Atropical rain forest - a study of irradiation and ecology at El Verde, Puerto Rico. U.S. Atomic Energy Commission. Wash. D.C.

Espey, W.H., et al., 1971. Galveston Bay project water quality modeling and data management. Phase II Technical progress report. TRACOR project 002-070, doc. no. T70-AU-7636-U.

Finenko, Z.Z. and V.E. Zaika. 1970. Particulate organic matter and its role in productivity of the sea. In: J.H. Steele (ed.) Marine Food Chains. U. of Calif. Press. Berkeley. p. 33-44.

Grøntved, J. 1960a. Taxonomical and productional investigations in shallow coastal waters. Medd. Danm. Fiskeri-og-Havunders, N.S. 3(1):1-17.

__________ 1960b. On the productivity of microbenthos and phytoplankton in some Danish fjords. Medd. Danm. Fiskei-og Havunders. N.S. 3(3):55-92.

Jones, D.K. 1960. Organic and inorganic carbon in the recent sediments of the open Gulf, barrier island and bay environments, Mustang Island, Texas. U. of Texas at Austin: a Thesis. 58 p.

Hellier, T.R. 1962. Fish production and biomass studies in relation to photosynthesis in the Laguna Madre of Texas. Publ. Inst. Mar. Sci., Univ. Tex. 8:15-21.

Hood, D.W. 1953. A hydrographic and chemical survey of Corpus Christi Bay and connecting water bodies. Texas A&M Univ. Research Project 40. College Station, Tx. 22 p.

Huston, R.J. 1971. Galveston Bay Project, compilation of water quality data July, 1968-Sept., 1971. Report to Texas Water Quality Board. TRACOR Project 077-005-05, Doc. No. T71-AU-9617-U.

Keefe, C.W. 1972. Marsh production: a summary of the literature. Contrib. mar. Sci. Univ. Texas. 16:163-181.

Maurer, L.G. 1971. The nearshore distribution and macromolecular contents of the dissolved organic matter of Texas estuarine and Gulf of Mexico waters. U. of Texas at Austin: a Dissertation. 96 p.

McMahan, C.A. 1968. Biomass and salinity tolerance of shoalgrass and manateegrass in Lower Laguna Madre, Texas. Jour. Wildl. Management. 32(3):501-506.

National Marine Fisheries Service. 1973. Texas Landings, 1972. U.S. Dept. Commerce. Wash. D.C.

Odum, E.P. 1971. Fundamentals of Ecology. 3rd Ed. Saunders, Philadelphia. 574 p.

__________ and H.T. Odum. 1959. Fundamentals of Ecology. 2nd Ed. Saunders. N.Y. p.72-73.

Odum, H.T. 1963. Productivity measurements in Texas turtlegrass and the effects of dredging an intracoastal channel. Publ. Inst. Mar. Sci. Univ. Texas. 9:48-58.

_________ 1967. Biological circuits and the marine ecosystems of Texas. In: T.A. Olson and F.J. Burgess (eds.) Pollution and Marine Ecology. Interscience, N.Y. p. 99-157.

_________ and C.M. Hoskin. 1958. Comparative studies of the metabolism in Texas bays. Publ. Inst. Mar. Sci. Univ. Texas. 5:16-46.

_________ , W. McConnell and W. Abbott. 1958. The Chlorophyll "a" of communities. Publ. Inst. Mar. Sci. Univ. Texas. 5:65-96.

_________, P.R. Burkholder and J. Rivero. 1959. Measurements of productivity of turtle grass flats, reefs and the Bahia fosforescente of southern Puerto Rico. Publ. Inst. Mar. Sci. Univ. Texas. 6:159-170.

_________ and R.F. Wilson. 1962. Further studies on reaeration and metabolism of Texas bays, 1958-1960. Publ. Inst. Mar. Sci. Univ. Texas. 8:23-55.

_________, R. P. Cuzon du Rest, R.J. Beyers and C. Allbaugh. 1963. Diurnal metabolism, total phosphorus, Ohle anomaly and zooplankton diversity of abnormal marine ecosystems of Texas. Publ. Inst. Mar. Sci. Univ. Texas. 9:404-453.

Pamatmat, M.M. 1968. Ecology and metabolism of a benthic community of an intertidal sand flat. Int. Revue ges. Hydrobiol. 53(2): 211-298.

_________ and K. Banse. 1969. Oxygen consumption by the seabed. II. In situ measurements to a depth of 180m. Limnol. Oceanogr. 14(2):250-259.

Patriquin, D. and R. Knowles. 1972. Nitrogen fixation in the rhizosphere of marine angiosperms. Marine Biology. 16:49-58.

Pomeroy, L.R. 1959a. Productivity of algae in salt marshes. Proc. Salt Marsh Conf. U. of Georgia Marine Inst. Sapelo Island, March, 1958. p. 88-95.

__________ 1959b. Algal productivity in salt marshes of Georgia. Limnol. Oceanogr. 4(4):386-397.

__________ 1960. Primary productivity of Boca Ciega Bay, Fla. Bull. Mar. Sci. Gulf and Caribb. 10(1):1-10.

Ragotzkie, R.A. 1958. Plankton productivity in the estuarine waters of Georgia. Publ. Inst. Mar. Sci. Univ. Texas. 6:146-158.

Reimers, R.S. 1968. A stable carbon isotopic study of a marine bay and domestic waste treatment plant. U. of Texas at Austin: a Thesis. 39 p.

Ryther, J.H. and W.M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science. 171:1008-1013.

Shepard, F.P. 1953. Sedimentation rates in Texas estuaries and lagoons. Bull. Am. Assoc. Pet. Geol. 37:1919-34.

__________ and D.G. Moore. 1955. Central Texas coast sedimentation: characteristics of sedimentary environment, recent history and diagenesis. Bull. Am. Assoc. Pet. Geol. 39:1463-1593.

Smalley, A.E. 1959. The growth cycle of Spartina and its relation to the insect populations of the marsh. Proc. Salt Marsh Conf. U. of Georgia Marine Inst. Sapelo Island, March, 1958. p. 96-100.

Smith, G.F. 1973. A preliminary investigation of the nutrient requirements of four Texas bay systems. In: E.M. Davis (ed.) Assessment of the primary ecological interactions in four Texas estuarine systems. Report to the Texas Water Development Board. IAC(72-73) 909.

Stansby, M.E. and A.S. Hall. 1967. Chemical composition of commercially important fish of the United States. Fishery Industrial Research 3(4):29.

Teal, J.M. 1959. Energy flow in the salt marsh ecosystem. Proc. Salt Marsh Conf. U. of Georgia Marine Inst. Sapelo Island, March, 1958. p. 101-107.

__________ 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology. 43(4):614-624.

Vaccaro, R.F. 1965. Inorganic nitrogen in sea water. In: H.E. Allen and J.R. Kramer (eds.) Nutrients in natural waters. Wiley. N.Y. 457 p.

Vinogradov, A.P. 1953. The elementary chemical composition of marine organisms. Memoir II. Sears Foundation for Marine Research.

Waite, T.D. 1972. Role of benthic plants in a fertilized estuary. Jour. Sanitary Engineering Div., A.S.C.E. 98:763-771.

Williams, R.B. 1964. Phytoplankton productivity at Beaufort, N.C. ASB Bull. 11(2):59.

__________ and M.B. Murdoch. 1966. Annual production of *Spartina alterniflora* and *Juncus roemerianus* in salt marshes near Beaufort, N.C. ASB Bull. 13(2):49.

__________ 1968. Compartmental analysis of production and decay of *Juncus roemerianus*. ASB Bull. 15(2):59-60.

Wilson, R.F. 1963. Studies of organic matter in aquatic ecosystems. U. of Texas at Austin: a Dissertation. 112 p.

Wood, C.E. and D.A. Jensen. 1973. Relationships between primary productivity and chlorophyll standing crop in a disturbed hypersaline environment. 36 Ann. Mtg. Amer. Soc. Limnol. Oceanogr. June, 1973. Abst.

References

Trace Elements and Toxic Compounds

Blakely, J. F. and H. L. Kunze. 1971. Reconnaissance of the chemical quality of the surface waters of the coastal basins of Texas. Texas Water Development Board Report 130.

* 9 Bookhout, C. G., <u>et</u>. <u>al</u>. 1972. Effects of Mirex on the larval development of two crabs. Water, Air and Soil Pollution. 1:165-180.

Bowen, H. J. M. 1966. Trace elements in biochemistry. Academic Press. New York.

8 Broad, A. C. 1964. Environmental requirements of shrimp. Biol. Prob. in Water Pollution. USDHEW-PHS. Publ. No. 999-WP-25. p 86-91.

10 Bryan, G. W. and L. G. Hummerstone. 1971. Adaptation of the polycheate <u>Nereis diversicolor</u> to estuarine sediments containing high concentrations of heavy metals. J. Mar. Biol. Assoc., U.K. 51:845-863.

2 Butler, P. A. 1964. Commercial fishery investigations. <u>In</u>: Pesticide wildlife studies, 1963. U.S. Fish and Wildlife Service. Circular 199. p. 5-28.

7 ____________ 1966a. Pesticides in the marine environment and their effects on wildlife. J. Appl. Ecol. 3(suppl.):253-259.

6 ____________ 1966b. The problem of pesticides in estuaries. Trans. Amer. Fish. Soc. 95(4suppl.):110-115.

33 Cabrera, J. 1971. Survival of the oyster <u>C</u>. <u>virginica</u> in the laboratory under the effects of oil drilling fluids spilled in the Laguna de Tamiahua, Mexico. Gulf Research Reports, 3(2):197-214.

1 Calabrese, A. 1972. How some pollutants affect embryos and larvae of American oyster and hard-shell clam. Mar. Fish. Rev. 34(11-12): 66-77.

* Reference numbers from Table V A-4

32 ________ and H. C. Davis. 1967. Effects of "soft" detergents on embryos and larvae of the American oyster (Crassostrea virginica). Proc. Nat. Shellfisheries Assoc. 57:11-16.

47 Chipman, W. A., T. R. Rice and T. J. Price. 1958. Uptake and Accumulation of Radioactive Zinc by marine plankton, fish and shellfish. Fish. Bull. 135, Fishery Bull. Fish and Wildl. Serv., U.S. 58:279-292.

28 Clarke, G. L. 1947. Poisoning and recovery in barnacles and mussels. Biol. Bull. 92:73-91.

27 Collier, A., S. Ray and W. B. Wilson. 1956. Some effects of specific organic compounds on marine organisms. Science. 124(3214):220.

Comar, C. L. and F. Bronner (eds.) 1962. Minera metabolism: and advanced treatise. Vol. II, The Elements. Academic Press. New York.

3 Daugherty, F. M. 1951. Effects of some chemicals used in oil well drilling on marine animals. Sewage and Industrial Wastes. 23(10):1285-1287.

43 Davis, H. C. 1961. Effects of some pesticides on eggs and larvae of oysters Crassostrea virginica and clams Venus mercenaria. Comm. Fish. Rev. 23(12):8-23.

19 ________ and P. E. Chandley. 1956. Effects of some dissolved substances on bivalve larvae. Proc. Nat. Shellfish. Assoc. 46:59-74.

15 Duke, T. W., et. al. 1970. A polychlorinated biphenyl (Arochlor 1254) in the water, sediment and biota of Escambia Bay, Fla. Bull. Environmental Contamination and Toxicology. 5(2):171-180.

17 Eisler, R. 1965. Some effects of a synthetic detergent on estuarine fishes. Trans. Amer. Fish Soc. 94(1):26-31.

4 ________ 1969. Acute toxicities of insecticides to marine decapod crustaceans. Crustaceana. 16:302-310.

37 ________ 1970a. Latent effects of insecticide intoxication to marine molluscs. Hydrobiologica. 36:345-352.

39 ________ 1970b. Acute toxicities of organochlorine and organophosphorus insecticides to estuarine fishes. U.S. Bur. Sport fish. and Wildl. Tech. Paper. 46:1-12.

38 ________ and P. H. Edmunds. 1966. Effects of endrin on blood and tissue chemistry of a marine fish. Trans. Amer. Fish. Soc. 95(2):153-159.

13 Epifanio, C. E. 1971. Effects of dieldrin in seawater on the development of two species of crab larvae, *Leptodius floridanus* and *Panopeus herbstii*. Marine Biol. 11(4):356-362.

14 ________ 1972. Effects of dieldrin-contaminated food on the development of *Leptodius floridanus* larvae. Marine Biology. 13(2):292-297.

Florin, M. 1960. Blood chemistry. *In* H. T. Waterman (ed.) The physiology of crustacea, Vol. I, metabolism and growth. Academic Press. New York. p. 141-154.

Frieden, E. 1972. The chemical elements of life. Sci. Amer. 227(1): 52-60.

12 Friend, M., *et. al*. 1973. DDE: Interference with extra-renal salt excretion in the mallard. Bull. Environ. Contam. Toxicol. 9(1):49-53.

36 Gardner, G. R. and G. LaRoche. 1973. Copper induced lesions in estuarine teleosts. J. Fish. Res. Bd. of Canada. 30(3):363-368.

Goldberg, E. D. 1972. Baseline studies of pollutants in the marine environment and research recommendations. Deliberations of the I.D.O.E. Baseline Conf.

Hahl, D. C., and K. W. Ratzlaff. 1970. Chemical and physical characteristics of water in estuaries of Texas, Sept., 1967--Sept., 1968. Texas Water Development Board. Report 117.

__________ 1972. Chemical and physical characteristics of water in estuaries of Texas, Oct., 1968--Sept., 1969. Texas Water Development Board. Report 144.

11 Hansen, D. J., et. al. 1971. Chronic toxicity, uptake and retention of Arochlor 1254 in two estuarine fishes. Bull. Environ. Contam. Toxicol. 6(2):114-119.

16 Harriss, R. C., D. B. White and R. B. McFarlane. 1970. Mercury compounds reduce photosynthesis by plankton. Science. 170(3959): 736-737.

18 Hemens, J. and R. J. Warwick. 1972. The effects of fluoride on estuarine organisms. Water Research. 6(11):1301-1308.

44 Hidu, H. 1965. Effects of synthetic surfactants on the larvae of clams M. mercenaria and oysters C. virginica. J. Water Poll. Cont. Fed. 37:262-270.

Holmes, C. W., E. A. Slade and P. J. McLerran. 1974. Migration and redistribution of Zinc and Cadmium in marine estuarine system. Env. Sci. and Technol. 8(3):255-259.

Jones, J. R. E. 1964. Fish and river pollution. Butterworths. London.

41 Lambou, V. W. 1972. U.S. Environmental Protection Agency. Report on the problem of Mercury emissions into the environment of the U.S. to the working party on Mercury. Sector group on the unintended occurence of chemicals in the environment, O.E.C.D.

31 Loosanoff, V. L. 1962. Effects of turbidity on some larval and adult bivalves. 14 Proc. Gulf and Carribb. Fish. Inst. p. 80-94.

45 Lowe, J. I. 1964. Chronic exposure of spot, Leistomus xanthurus, to sublethal concentration of toxaphene in seawater. Trans. Amer. Fish. Soc. 93(4):396-398.

34 __________ 1965. Chronic exposure of blue crabs, C. sapidus to sublethal concentrations of DDT. Ecology. 46:899-900.

30 __________, et. al. 1971. Chronic exposure of oysters to DDT, toxaphene and parathion. Proc. Nat. Shellfish. Assoc. 61:71-79.

23 Marvin, K. T., C. M. Lansford and R. S. Wheeler. 1961. Effects of copper ore on the eoclogy of a lagoon. Fishery Bull. Fish and Wildl. Serv., U. S., Circular 184:153-160.

Millero, F. J. 1969. The partial molal volumes of ions in seawater. Limnol. Oceanogr. 14(3):376-385.

22 Modin. J. C. 1969. Residues in fish, wildlife and estuaries. Pestic. Monit. J. 3:1-7.

Nicol, J. A. C. 1967. The biology of marine animals. Ch. 2 Water salts and minerals. Pitman. London. p. 28-83.

20 Nimmo, D. R., et. al. 1971. Toxicity and distribution of Arochlor 1254 in the pink shrimp, Penaeus duorarum. Marine Biology. 11(3):191-197.

35 Odum, W. E., G. M. Woodwell and C. F. Wurster. 1969. DDT residues absorbed from organic detritus by fiddler crabs. Science. 164:576-577.

Parker, P. L. 1962. Zinc in a Texas bay. Publ. Inst. Mar. Sci., Univ. Tex. 8:75-79.

__________, A. Gibbs and R. Lawler. 1963. Cobalt, Iron and Manganese in a Texas bay. Publ. Inst. Mar. Sci., Univ. Tex. 9:28-32.

21 Parrish, P. R., et. al. 1972. Effects of Arochlor 1254, a PCB, on oysters, Crassostrea virginica. ASB Bull. 19(2):90.

24 Price, T. J. 1964. Accumulation of radionuclides and the effects of radiation on molluscs. Bio. Prob. in water pollution. USDHEW-PHS Pub. 999-WP-25. p. 202-210.

26 Rabin, E. H. and F. C. Schwartz. 1970. Ocean dumping--a national policy. Rept. to the President by the Council on Environmental Quality.

25 ____________ 1972. The pollution crisis--official documents. Oceana Pub. New York.

26 Raymont, J. E. G. and J. Shields. 1964. Toxicity of Copper and Chromium in the marine environment. In E. A. Pearson (ed.) Advances in water pollution research. Vol. 3. Macmillan. New York. p. 275-290.

29 Shuster, C. N. and B. H. Pringle. 1968. Effects of trace metals on estuarine molluscs. Proc. First Mid-Atlantic Indust. Waste Conf., Univ. Delaware. CE-5:285-304.

5 ____________ 1969. Trace metal accumulation by the American eastern oyster, Crassostrea virginica. Proc. Nat. Shellfish. Assoc. 59:91-103.

Stansby, M. E. and A. S. Hall. 1967. Chemical composition of commercially important fish of the United States. Fishery Industrial Research. 3(4):29.

48 Tucker, R. K. and D. G. Crabtree. 1970. Handbook of toxicity of pesticides to wildlife. Bur. Sport Fish. and Wildl., Denver Wildl. Res. Cen. Resource Pub. 84. 131 p.

42 Ukeles, R. 1962. Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl Microbiol. 10:532-537.

Vinogradov, A. P. 1953. The elementary chemical composition of marine organisms. Memoir II, Sears Foundation of Marine Research.

40 Woodwell, G. M., C. F. Wurster and P. A. Isaacson. 1967. DDT residues in an east coast estuary: a case of biological concentration of a persistant pesticide. Science. 156:821-824.

References

Abundances of Element Table 19

Arrhenius, G. N.D. Selected biogeochemical data. Scripps Inst. Oceanography. La Jolla, Calif. paper

Bowen, H.J.M. 1966. Trace Elements in Biochemistry. Academic Press: New York.

Carriker, M.R. 1967. Ecology of estuarine benthic invertebrates: a prespective. pp442-487. In: Estuaries. Amer. Assoc. Advance. Sci. Putl. No. 83. Wash., D.C.

Comar, C.L. and Bronner, F. (eds.) 1962. Mineral Metabolism: an Advanced Treatise. vol. II: the elements (part B). New York: Academic Press.

Cronin, L.E. 1967. The role of Man in Estuarine Processes. Estuaries. G.H. Lauff (ed.) Amer. Assn. Adv. Sci., Publ. #83:667-689.

Darnell, R.M. 1967. Organic detritus in relation to the estuarine ecosystem. pp 376-382. In: Estuaries. Amer. Assoc. Advance. Sci. Publ. No. 83. Wash., D.C.

Florin, M. 1960. Blood Chemistry. In: The Physiology of Crustacea. T.H. Waterman (ed.) vol. I: Metabolism and Growth. New York: Academic Press. pp. 141-154.

Frieden, E. 1972. The Chemical Elements of Life. Sci. Amer. vol. 227(1) 52-60.

FWPCA 1968. Report of the Committee on Water Quality Criteria. National Technical Advisory Committee on Water Quality Criteria. Wash., D.C. pp. 32-59.

Goldberg, E.D. 1972. Baseline Studies of Pollutants in the Marine Environment and Research Recommendations. Deliberations of the International Decade of Ocean Exploration Baseline Conf.

Gunter, G. 1967. Some relationships of Estuaries to the Fisheries of the Gulf of Mexico. Estuaries, G.H. Lauff (ed.). Amer. Assn. Adv. Sci. Publ. 83:621-638.

Jenkins, D.W. Biological Monitoring of the Global Chemical Environment. 54pp.

Jones, J.R.E. 1964. Fish and River Pollution. London: Butterworth.

Kinne, O. 1967. Physiology of estuarine organisms with special reference to salinity and temperature: General aspects. In: Estuarines. AAAS Publ. 83:525-540.

McHugh, J.L. 1967. Estuarine Nekton. Estuaries. G.H. Lauff (ed.) Amer. Assoc. Adv. Sci. Publ. 83:581-620.

McKee, J.E. and H.W. Wolf. Biological Pollutants, 1963: Coliform bacteria in water quality criteria. Resources Agency of Calif., Publ. 3-A:308-315.

Mahler, H.R. and Cordes, E.H. 1971. Biological Chemistry. Harper and Row, Publishers.

Milliero, F.J. The Partial Molal Volumes of Ions in Seawater. Inst. of Mar. Sci. Univ. of Miami, Cont. #000.

Nicol, J.A.C. 1967. The Biology of Marine Animals. Ch. 2 Water, Salts and Minerals. Lond: Sir Isaac Pitman & Sons Ltd. pp. 28-83.

Stansby, M.E. and Hall, A.S. 1967. Chemical Composition of Commercially Important Fish of the United States. Fishery Industrial Research, vol. 2(4)p.29. U.S. Dept. of the Interior, Fish and Wildlife Ser., Bur. of Commercial Fish.

Vinogradov, A.P. 1953. The Elementary Chemical Composition of Marine Organisms. Memoir II. Sears Foundation for Marine Research.

__________. 1971. Marine Environmental Quality. Rept. of a Special Study held under the auspices of the Ocean Science Committee of the NAS-NRC Ocean Affairs Board. National Academy of Sciences.